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Studying the Effects of Roads Geometry and Design Parameters on the Pavement Drainage System

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Abstract

Background: Water floods have a considerable impact on roads sustainability by creating roads cracks, breaking down and holes, and failure for some other parts. The existence of good drainage system serviced the road and draining the water resulted from rain floods is crucial. These significant influences can be classified as positive or negative, low, moderate, or high. *Aim and Objectives:* This paper discusses the water floods and rainfall effects on roads and highways in Jordan as well as the drainage system on road sustainability and performance. The main aim of this paper is to investigate and analyse water as rainfall or floods affecting roads and highways in Jordan. The importance of this study is represented by studying and analysing the effects of rainfall and water floods on road construction and sustainability in Jordan after the latest high rain sizes of this winter and water floods, which affect the roads and highways in a good percentage. The other importance of the study is represented in offering solutions to problems caused by the environmental effects, specially floods and high rainfall rates. *Methodology:* all data and information about status of Jordanian roads during winter and floods are collected from real cases of about 40 main and semi-main roads in Jordan. *Results and Conclusions:* A good drainage system and repair operations and maintenance generally have a positive impact on road sustainability and survival age. The effects of slopes of the road and surface of the asphalt, rainfall intensity, and water flow velocity on drainage length and drainage time and water depth are discussed here.

Keywords: Roads Constructions; Rainfall Intensity; Cracks; Slope; Drainage System; Sustainability; Pavement.

1. Introduction

The quality of street and transportation operations via such streets against water floods and high precipitation forces and different impacts can be estimated by measuring its ability to offer safety and good reliability for transportations and travellers to different separations with enormous adaptability and with low expenses. Effective street design is a decent measure for feasible improvement. Before, the thought of the ecological effect and supportability issues of transport was commonly negligible. As of late, the decline of ecological weights requests an imperious re-evaluation of the principle natural viewpoints in road constructions, structure, design, and development. By and large, there are two principle decisions accessible for road constructions: either inflexible (rigid) black-top or flexible black-top asphalts. Each contending industry (cement and asphalt) is attempting to persuade that their solutions are environmentally friendly and increasingly economic. Environment conditions and road use capacity ought to be considered during its life cycle like crude or raw materials utilized in road construction, starting change, producing, maintenance processes, support, reusing, and removal. Floods and water also affect road conditions and

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building layers. Floods and high water intensities effects include vegetation, soil, sand, rocks, drainage conditions, general stability of the region, and road sustainability.

Although water could also be a vital liquid for our planet, it's long been recognized as a significant enemy of roads. Road literature provides an upscale history of the disastrous effect of water on a region that protected well against such heavy rainfall. The drop of water explodes when it affects bare soil that begins to wear. Water corrosion increases with its volume and flow speed (flow speed). The degree of soil corrosion resistance depends on several factors. First, the kind of soil and, therefore, the size of particles is vital. Soil stability depends on rock, sand, silt, and clay ratios within the soil. A rock-like bank that appears within the image stable with little corrosion. The second factor is soil cover, specifically vegetation cover. The vegetation breaks down a raindrop and dissipates its destructive energy before it hits the soil. Vegetation also slows the flow of surface water, keeping speeds low, and reducing wear [1]. Many researches discussed the issue of floods and drainage systems and their effects on roads and streets; Life Cycle Assessment (LCA) studies for roads and their effects on the environment also technical and economic aspects in road construction are presented in Moretti et al. (2013) [2]. Maintenance operations performed in winter and works on roads are often considered as crucial for achieving an inexpensive level of motorist safety and public mobility on highways in cold regions, as discussed by Shi et al. (2014) [3]. In Mahoney et al. (2015) [4] study, some issues in analysing the corrosive effects of chemical methods were addressed, also identify the value of corrosion caused by treatment methods, alternative techniques, and products, such as, but not limited to, rust inhibitors, cost, and effectiveness were all addressed. Safety and mobility of passengers from the general public require highway maintenance within the best winter. Building Information Modelling (BIM) to quantify the environmental impacts and effects on road construction projects and maintenance was presented in Marzouk et al. (2017) study [5].

The model is taking into consideration the general life cycle of the construction project, which had been divided into seven phases: transportation phase, construction phase, maintenance phase, operational phase, manufacturing phase, recycling phase, and deconstruction phase. The study targeting case study counting on demonstrate the applicability of the proposed model [5]. The developed model can solve a significant problem for road construction project teams who want to assess the environmental impact indicators associated with their project before the start of the execution of their projects. Ghana and other African countries suffer from the effects of climate change and floods on roads and the transport, road maintenance, and construction sector [6]. It was noted the effect of the roads on the environment in Malaysia and vice versa has been examined on the effects of the environment on the roads and the costs of its construction and quality [7]. These environmental impacts on roads are represented by the high cost of construction due to tropical environments. Such defects will be required, such as further cutting, packing, tunnels, and mitigation measures. Land flatter/marshes - these sections will require a high road base and more canals, bridges, and drainage. It will also cause a lack of investment in the maintenance of roads - pit and landing. An assessment of the impact factors and environmental effects on asphalt and concrete pavements was presented by Winston et al. (2020) [8]. Two specific case studies were analysed here, each with alternatives available for pavement construction, the traditional flexible pavement designed according to national standards versus the modern steel-fibres (SFR-RCC)-Compressed concrete paving. These alternatives were analysed using the GABI Programme to assess their environmental aspects related to the concept of sustainability as well as the effects of environmental factors on both models. Following a detailed discussion of the main findings obtained in these studies, conclusions and recommendations were formulated for an adequate selection of building alternatives [8]. In the present paper, the main issue discussed is the floods and rainfall effects on roads, and a redesign of road geometry is performed using accurate engineering formulas and design conditions.

The authors in Choo et al. (2020) [9] stated that stormwater overflow from metropolitan advancement makes undesired effects surface waters which effect on roads and transportation operations, including release of toxins, disintegration, and loss of living space. A treatment train comprising of porous interlocking solid asphalt and underground stormwater reaping was observed to evaluate water quality enhancements. The Spatial Runoff Assessment Tool (S-RAT) and Flood Inundation model (FLO-2D model) to figure the floods level in metropolitan territories brought about by precipitation and utilize the floods rate and its effects on roads and drivers were discussed in Gissing et al. (2019) research [10]. Because of the check, the outcome was like the real floods, and when a similar precipitation happened inside the scope of the objective territory, it was affirmed that there were segments that couldn't be passed and segments that could be passed easily. Hence, the outcomes proposed in this examination will be useful for the driver's course determination by utilizing the metropolitan flood harm investigation and vehicle driving pace investigation.

The properties of streets that may have affected driver choices to enter floodwaters and the survivability of individuals in vehicles that did as such and closes by talking about arrangement suggestions are discussed here [11]. Attributes most every now and again present were little upstream catchment length that may impact the pace of ascent of floodwaters; the nonattendance of side of the road blockades; profound floods quickly neighbouring the street; the nonappearance of lighting; plunging street levels that lead floodwaters to increment once a vehicle enters them; the absence of control and guttering and the powerlessness of drivers to effectively pivot. Every one of these elements were seen in at any rate half of the cases examined and give a danger based methods for evaluating different destinations powerless against floods yet where fatalities have not been seen to date [11].

A free coupling of two models is finished. For metropolitan waste, PCSWMM, and for traffic, VISSIM is utilized was investigated in Gallaway et al. (1971) [12]. The two models are adjusted for a current circumstance on precipitation function of August 3, 2013, and afterward utilized for expectation of future situation dependent on 50-year and 100-year return times of precipitation. Affectability investigation of VISSIM is performed. Areas and lengths of street segments, where ponding occurs for the future situation, are distinguished utilizing PCSWMM. These lengths are then set apart in VISSIM as low-speed regions, and postponements are estimated. Investigation of PCSWMM shows that for 100-year return period, there is most extreme 0.318 ha-m (3180 cubic meters) water put away in the sorrows of the street after 10 h of precipitation. Examination of VISSIM shows that for a 100-year return period, there is a most extreme deferral of 35 min on NIPA to Hasan Square part of University Road. A Warm Mix Asphalt (WMA) was viewed in Yu and McNown (1963) [13] study, as moderately another innovation, which empowers the creation and compaction of black-top solid combinations at temperatures 15-40 °C lower than that of customary hot blend black-top. The Resilient modulus (Mr) which can be characterized as the proportion of pivotal throbbing pressure to the comparing recoverable strain, is utilized to assess the overall nature of materials just as to produce contribution for asphalt plan or asphalt assessment and investigation. The gathered examples were exposed to the backhanded strain test by pneumatic continued stacking framework (PRLS) to portray the versatile modulus. The test conditions (temperature and burden span) just as blend boundaries (black-top substance, filler substance and type, and air voids) are considered as factors during the example's arrangement. It was discovered that such sort of black-top has great details to oppose some natural changes.

The effects of heavy rainfalls and water floods on slopes and roads have already been identified as major road disturbances. Impact of rain on roads factors like sliding resistance and, therefore, the link between heavy rain and road stability has got to be taken care of by road managers, without the other effects of global climate change. Road assets are subject to many impacts. Its operations are at high risk because of weather-related effects like rains, which increase soil moisture and groundwater, and/or higher average rainfall results in more landslides that need extensive repairs and cause short or long delays to be closed. Possible consequences include damage to road assets, road users, and road freight. The paper will discuss and analyse the rainfall problem and its parameters and their effects on increasing or decreasing floods on roads and their effects on such phenomenon. In the next section data collected required for the study is demonstrated and tabulated. A mathematical formulas are presented and developed to study the effects of roads' materials and geometry factors on roads floods. On the next step, the analysis of the effect of such parameters are presented and discussed. Finally conclusions are stated. A comparison and analyse of the results will be performed here for more investigation.

1.1. Rainfall Problem Analysis

From a privileged point of view, the road becomes slippery when conditions prevail if water fishes to the surface contact area of the road tire, when corrosion is slippery in nature for a replacement surface and is polished off-road by traffic, and/or when the vehicle speed is high enough to scale back contact (or available friction) or to eliminate it dynamically below the specified level of car manoeuvres. Most automobile crashes involving skidding are just because of the unfortunately combined set of wet pavement and are experienced by the driving force. For manoeuvring performance (brake, turns, acceleration) at very high speeds for conditions. The frequency of this range of cases has increased sharply within the previous couple of years, with increases in traffic volumes and better average vehicle speeds. When the surface of the road becomes wet, this condition is no longer valid for certain surface conditions and types, but the only variable state is the presence of water between the tire of the car and the pavement. Therefore, the study of factors affecting the thickness of the water membrane is crucial. Rainwater forms a layer of a thickness of growth where it flows to the edge of the sloping surface, as shown in Figure 1, which represents the base of this analysis. This water is dangerous for drivers due to low tire friction with wet surfaces and poor visibility through the spray and heavy spray. The need to quickly remove rainwater from the most important routes on multi-track highways is more water-intensive in the outer corridors. In addition, providing adequate materials on the road surface [14].

Water will flow across a surface along a line, the resultant slope of which depends on the transverse cross slope or super-elevation and longitudinal gradient. The length of the flow path is given by:

$$L_f / W = \frac{S_2}{S_1} \tag{1}$$

Where W is the pavement width (ft), and L_f is the Drainage length, S_2 is the cross slope, and S_1 is the longitudinal slope, and S_3 is the slope of the resultant flow path (Shown in Figure 1).

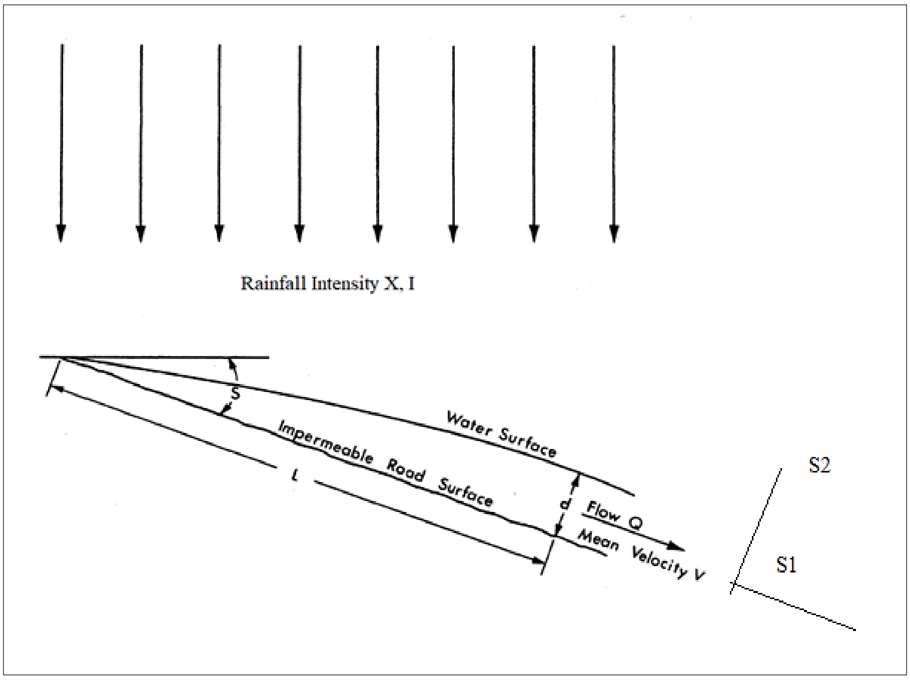

Figure 1. Water flew over an impermeable Road surface [14]

If a rainfall of constant intensity falls over a pavement surface, a series of events were taken place as follows: At first, much water is needed to fill the surface intersections before runoff occurs. This quantity is referred to as depression storage and is measured in size per unit area or average depth per inch. It depends on the initial wetness of the surface, the surface texture, and the distortions in the surface and the cross-slope. Secondly, the thin layer of water on the surface is called a fixed period of the run, except for those needed to store depression, surface retention. It contains the same quantities that can also be expressed as a value at a point or center over the area. Surface detention is primarily based on cross slope and intensity [14].

In Yu and McNown (1963) and Izzard and Hicks (1947) [13, 14] works, a description of the temporary increase in runoff, which occurs after rainfall stops. It indicates that the effect of rainfall increases turbulence and thus increases the resistance of water flow to the surface during the season. Additionally to low traction, surface capture water contributes primarily to the matter of spraying during precipitation. Reduced water storage leads to spray effects after a surface runoff, which will last for an extended period and cause noticeable visual defects because of dirty water spray on the windshield of the vehicle. The equation states that if the rain lasts long enough for the entire area to contribute, the runoff is equal to the rate of the show (excessive precipitation). For an intangible area, runoff equals the amount of rainfall that is obtained as follows [14]:

$$Q_e = \frac{IWL}{43200} \tag{2}$$

Where W = width of drainage area (ft), I: is the rainfall intensity (in/hr), and L = length of drainage area (ft), Q = flow rate (ft^3/sec);

The time required for the flow to be 97 percent of the supply, i.e., the time to equilibrium, was found to be:

$$t_e = \frac{2\ (0.0071 + c)L}{60\ \ Q_e^{2/3}\ \ S^{1/3}} \tag{3}$$

Where t_e: is the equilibrium time (Minute); Q_e: is the equilibrium discharge (ft^3/min), S: is the slope (ft. /ft.)%; and c is the retardance coefficient ranging from 0.007 for very smooth asphalt pavement to 0.017 for tar and gravel pavement, and L = length of drainage area (ft.).

The general equation relating water depth to drainage length, rainfall intensity, and the slope was determined by the British units to be:

$$d = \frac{0.005(LI)^{0.47}}{S^{0.20}} \tag{4}$$

Where *d*: is the water depth (in); *I*: is the rainfall intensity (in/hr.); *L:* is the drainage length (ft.), and *S:* is the slope (ft. /ft.)% or slope %.

This equation includes determining numerical values for the coefficient and exponents in the basic continuity equation, and surface flow equations of Chezzy and Manning cited earlier. Equation 4, in which the water depth (*d*) is measured from a datum plane at the top of the texture, would only be valid for conditions when the water depth was above the top of the texture; the reason being that L, I and S are always positive thus precluding a negative (water depth below top of the texture).

2. Materials and Methods

To perform the task and achieve goals of the research the following steps were followed, Figure 2 below shows the steps followed during the study.

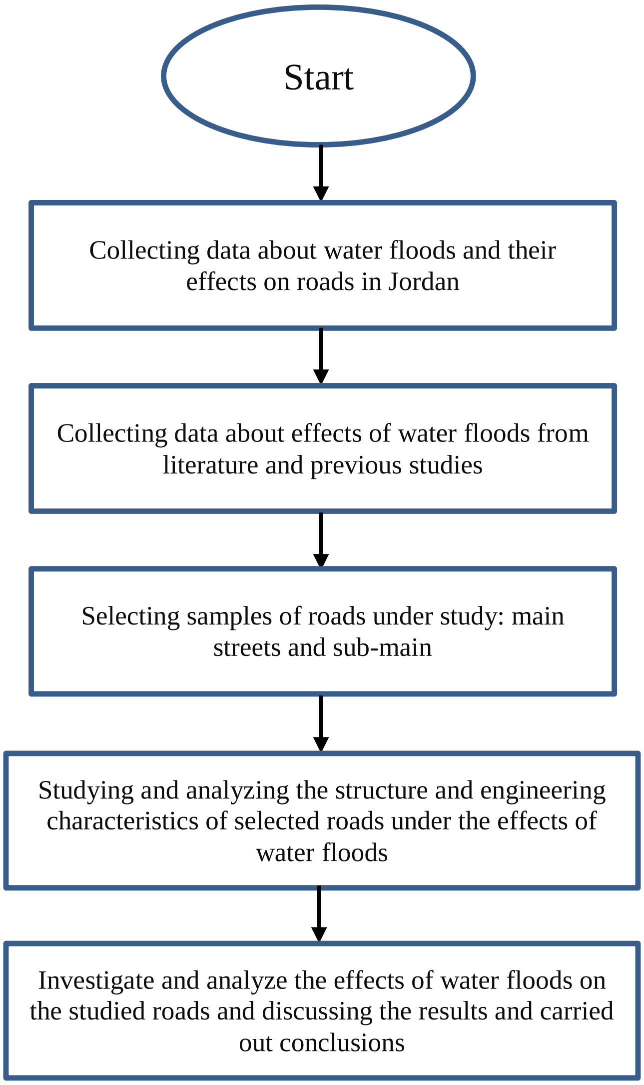

Figure 2. Study methodology flow chart

The data collected about the Jordan case study of rainfall last winter (2018/2019), which affects most of the Jordanian roads and causes a stoppage in traffics and airport highway, are shown in Tables 1 and 2 below, these tables represent the average values of about 40 studied roads in Jordan. Figure 3a, b, and c shows a map of Jordan, Amman area and the studied streets-Airport Highway and others beside.

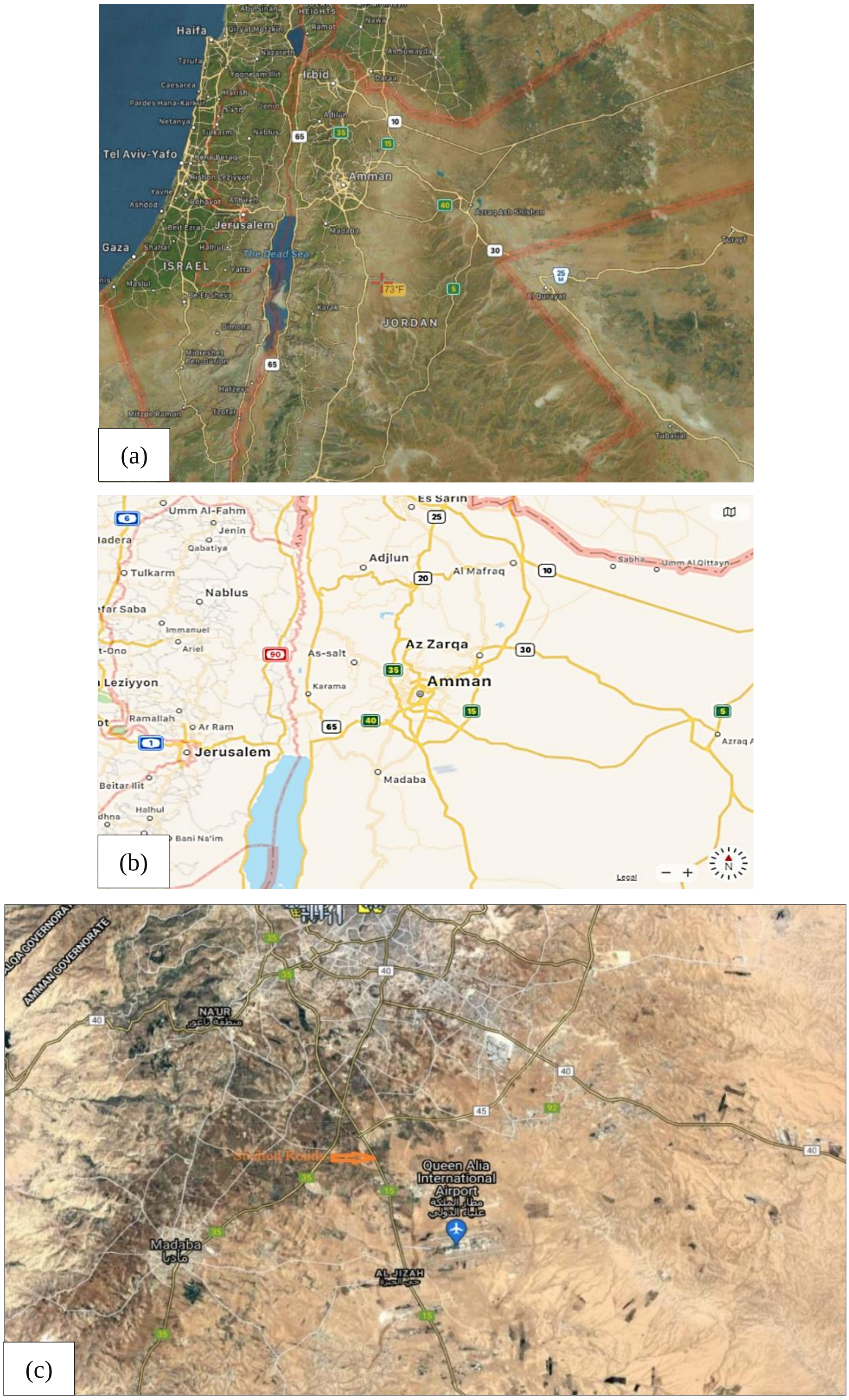

Figure 3. Google Map for (a) Jordan; (b) Amman and (c) the studied roads

Tables 1 and 2 which contained the data collected about water floods in some studied streets presented here.

Table 1. Data collected from Jordan (Tar asphalt and gravel pavement)

Q (ft³/s)	*I* (in/hr)	*S*(ft/ft)	S_1	S_2	V_e (ft³)	*W*(ft)	*L*(ft)	*C*(tar)
1.18	4.00	0.01-0.1	0-15%	0.0625	0.045-2.5	45	640	0.017

Table 2. Data of (very Smooth asphalt roads)

Q (ft³/s)	*I* (in/hr)	*S*(ft/ft)	S_1	S_2	V_e (ft³)	*W*(ft)	*L*(ft)	*C* (smooth asphalt)
1.18	4.00	0.01-0.1	0-15%	0.0625	0.045-2.5	45	640	0.007

3. Results and Discussion

The results depending on applying the resulted mathematical model data collected, and then discussing the effects of water (rainfalls and water floods) on Jordanian roads and generating the following road defects: cracks, high stresses, erosion, wear, corrosion, and damage to road structure.

3.1. Floods Effects

By applying Equations 1 to 4 on collected data. The results are shown in Figures 4 to 6. Figure 4 shows the drainage length in (ft) for a segment of the studied roads exposed to floods in winter in Jordan (for both tar and smooth asphalt road types). It can be noticed that as the longitudinal slope % or degree increases, the drainage length decrease for different widths of road. It can be seen that as the longitudinal slope of the road increases, the drainage length decreases. In addition, as the width of the road decreases, the drainage length decreases too.

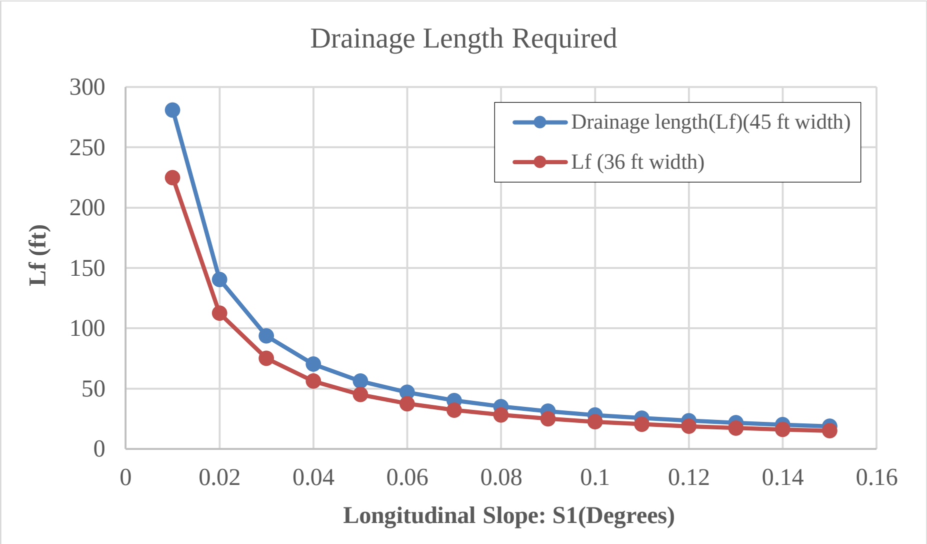

Figure 4. Drainage length versus longitudinal slop at different values of road width

By applying Equation 3 for the real case of rainfall flow rate in 2019/2020, and depending on data of Tables 1 and 2, the drainage length is required to be 240-280 ft. So, here, it can conclude that the road design is good because the longitudinal slope should be less and should be around 17%. The road should be reconstructed or redesigned, or we can control the floods by the width slope. This case explained why floods occurred, and the water moves more distance on roads to be discharged or running off. Figure 5 shows the relation between the time needed for runoff of water and the quantity of water on the surface of the road, and it can be noticed that as this quantity increase the time required is also increased, this also explained the extra time needed for floods in studied roads in Jordan.

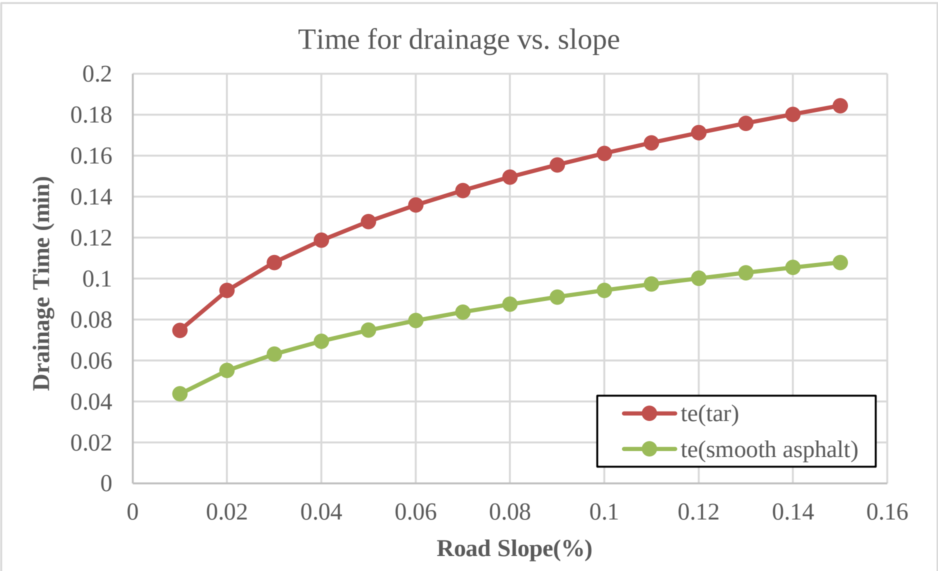

Figure 5. Time needed to runoff of water on studied roads as a function with a flow rate

Figure 5 can be used to calculate the time required for runoff the massive quantity of rainfall in the season 2019/2020. Also, Equation 4 can be used to calculate the water depth during rains. Figure 6 shows the relation between the water depth (in) with slope at some values of rainfall intensity (in/hr.). It can be noticed that as the rainfall intensity increases, the water depth increases, and also this explains the height or water depth during rainfall in Jordanian roads, and this will increase if we have a bad drainage system as found by inspection of roads studied. So the drainage system and network should also be maintained periodically, especially before starting any new winter season.

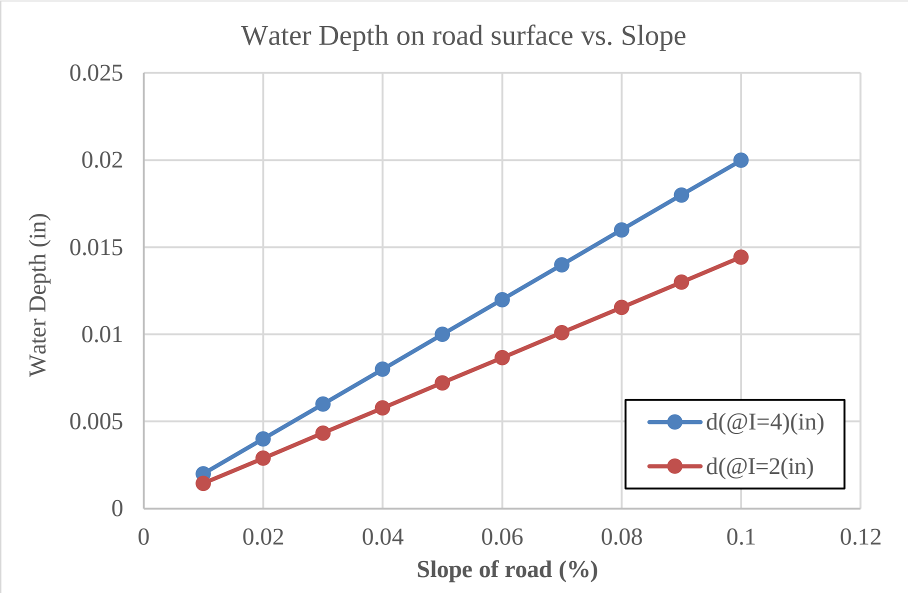

Figure 6. Water depth as a function with slope at different values of rainfall intensity

3.2. Drainage System Classification

Poor drainage and loss of maintenance of solid and flexible types of pavements when the construction section contains free water. The quality of the drainage is an important parameter affecting the performance of the highway quay. Poor sanitation on roads leads to a large number of costly repairs or alternatives long before the design age. Table 3 shows the relationship between the capacity of the class drain and the assessment of non-personal drainage quality.

Table 3. The relation between layer's drain ability and subjective drainage quality rating [15, 16]

Drainage Rank	Drainage Quality	Time of Water removed
1	Excellent	2 hours
2	Good	1 day
3	Fair	7 days
4	Poor	1 month
5	Very poor	Water will not drain

Table 4 and Figure 7 show the classification of drainage system of some selected streets and highways in Jordan, these results are collected by observing and following up the time needed for removing water out of the surface of such streets. The study includes about 40 streets and roads in Amman, airport highway and its sub-streets.

Table 4. Classification of Drainage system for 40 selected streets in Amman (2019)

Drainage Quality	Number of streets
Excellent(2 hours)	3
Good (one day)	20
Fair (7 days)	11
Poor (one month)	5
Very poor (Water will not drain, more than 1 month)	1

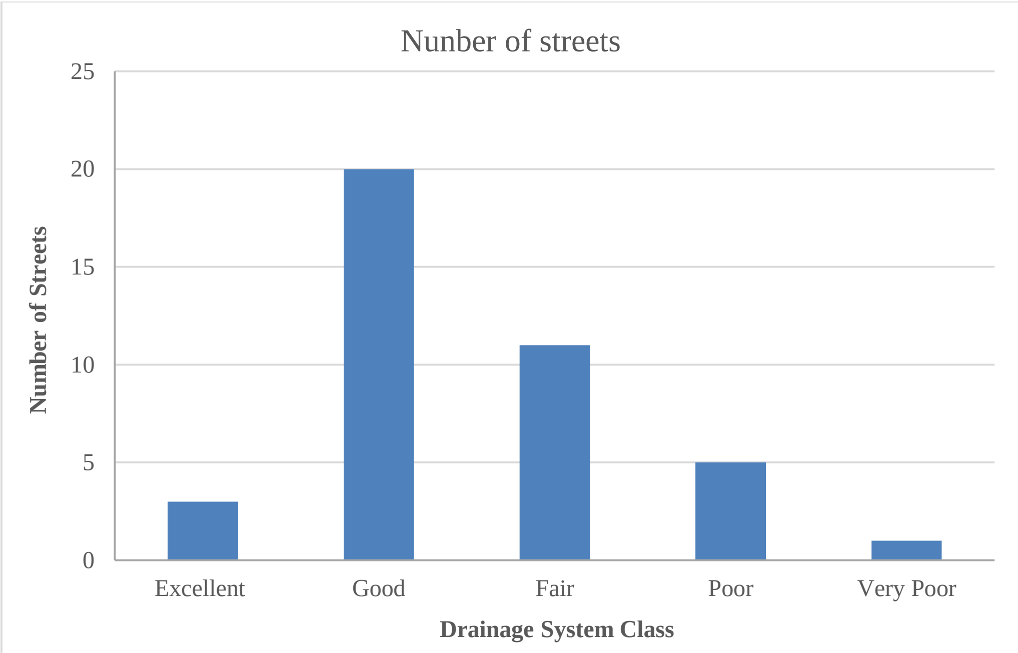

Figure 7. Classification of drainage system of some 40 selected streets and highways in Jordan

It can be noticed that most of studied samples of Amman streets are lie in the class of good drainage system, 12 of them are fair, while five of them are poor and one is very poor.

4. Conclusion

This work presented and analysed rainfall and floods effects on roads. The drainage system plays a vital role in the process of preventing floods and avoiding road defects. It can be concluded that weak road drainage facilities on highway structures have many devastating effects on the user economy, as functional and structural failures due to poor drainage increase travel time and hinder human performance at the society level. The effect of poor drainage on the road is extremely harmful. It causes the failure of the road in different ways. The correct road drainage system increases road life. However, an improper drainage system leads to failure of the road at its beginning. Adequate road drainage should, therefore, be taken into account during road construction. Therefore, appropriate design, construction, and maintenance practices should be adopted to maintain road drainage. Also, results showed the relation between the water depth (in) because of rainfall intensity (in/hr.). It is found that as the rainfall intensity increases, the water depth increases, and also this explains the height water level or water depth during floods in Jordanian roads, and this will increase if the street has a bad drainage system as found by inspection of roads studied. So the drainage system and network should also be maintained periodically, especially before starting any new winter season. It can conclude that the drainage length in (ft.) for a segment of the studied roads exposed to floods last winter in Jordan. It can be noticed that as the longitudinal slope % increases, the drainage length decrease. The drainage systems should be ready all the time to discharge any excess water floods out of the roads and so prevent road failures and reducing risks of users and increasing safety.

5. Declarations

5.1. Data Availability Statement

The data presented in this study are available in article.

5.2. Conflicts of Interest

The authors declare no conflict of interest.

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